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DESIGN & DEVELOPMENT OF SUCTION BASED WALL-CLIMBING SYSTEM

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ABSTRACT

In the today's scenario, Climbing robots use suction cups for maintaining the stability on vertical wall surfaces. Most of the climbing robot's that uses suction cup employs a remotely located huge suction generator to produce the suction force for adhering to the wall surface. The negative suction force to the suction cups is delivered through lengthy tube that affects the dynamic leveling and steadiness of climbing automaton. In the present research work, the climbing robot uses suction drag principle and includes a suction cup integrated with a suction motor, drive motors and an embedded controller, which might go on smooth vertical wall surfaces. This paper deals with the negative suction pressure to stick on the wall. It conjointly approves regulating the cup's terrible strain by means of continuous feedback. CATIA 3D modeling software is employed to style, simulation of the suction cup. This paper examines its integral numerical examination, hence the wall-climbing robotic system. The volume of suction force and related suction pressure is generated, which is required by the suction cup to work on drag principle. Matlab Simulink model is used to validate the suction motor speed and suction pressure generated with respect to time-period. The experimental results prove that the generated suction pressure within the suction cup machine is to be -6.63 kPa for sticking smoothly on vertical wall surfaces. The self-weight of the suction cup is about 2Kg. The climbing robot can move freely on vertical wall surface by controlling the speed of the suction motor and thereby reducing the pressure to around -3 kPa. This climbing robot can take additional of 5kgs of extra payload for its applications. The drop off suction pressure is found to be-1.82kPa.

KEYWORDS: Climbing Robots, Negative Suction Pressure, Suction Drag System & Stability

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Original Article

1. INTRODUCTION

Climbing robot with suction force enabled motors play out various tasks like examination and support of tall structures, examinations of cracks and welds, testing, monitoring and so on [1-5]. The wall climbing robotic system with control automation reachable as on date have confined capacities. Striking alternatives of the robotic system proves the maximum weight carrying capabilities. The major design strategy includes 1) On-board Suction Generator, 2) lightweight weight; 3) Automatic activity 4) The robot framework will have the most noteworthy payload capacity and safe quality. One in everything about chief troublesome undertakings is to build up a right bond component to affirm that the robot framework sticks to wall surfaces loyally while not relinquishing the quality.

2. LITERATURE SURVEY

The wall climbing robot frameworks with a sliding drag principle, which uses pressure leaks to traverse on surfaces. These robots are designed for particular applications and uses various other adhesion based climbing robots with

negative weight frameworks, air mechanical gadgets, the reptile frameworks, slippy segments (crawling) [6], wheel-driven robots, chain-driven robots, and three-legged machines. Forget on smooth surfaces, the vacuum framework driven by wheels seems to be the most straightforward goals additionally; the mechanical development is nearly simple. Our mechanical build of the ascension robot itself comprises of a suction chamber that slides over the effortless surfaces using individually driven wheels. The authors Tae Won Seo. Et al has built up AN underneath spurred standard ascension machine with level dry stuff cement [7]. The most advantages square measure rapid, high payload, and dexterous movements anyway it's the hindrances of vertical to roof interpretation development and defilement made thanks utilizing of stuff. Guang Zhao Cui et al. anticipated the appearance of an ascension robot upheld Electrically sensible Adhesion Technology, that has the advantages of minimal size, climb various surfaces, expend low force anyway it's the drawbacks of frightfully low trip speed, limited burden capacity, and needs high voltage (1-5 kV).

Zhiqiang nuclear number 83 et al., utilized attractive fascination grip Technology that has advantages of Stability and High burden ability [8]. It cannot be utilized on non-ferromagnetic surfaces and at high temperatures as polarization property differ. JiajieGuo et al. utilized Magnetic Wall climb innovation machine for testing huge attractive fascination structures [9]. The machine has enough speed and shrewd burden dealing with ability anyway it's appropriate only for attractive fascination structures. Attractive property variation will occur at high temperatures. Hwang Kim et al. used a half-tracked wheel mechanism of twelve consumption pads per wheel [10]. Xiao vim fowl family et al. utilized Bernoulli's statute to set off non-contact attachment [11]. Its advantages of high force/weight quantitative association (as excessive as 5), minimal effort commonplace pleasant beneath entirely sudden surface conditions, and measured quality anyway, it is no longer geared up to deal with a higher payload. Emir Degani et al., used Single mechanism Technology, however, the system is a smaller amount stable and therefore the load dealing with capability is much less [12]

Jizhong Xiao et al., utilized Vacuum principally based wheel drag framework innovation with reasonable payload capacity and reasonable solidness. Anyway, it needs a great deal of intensity, since erosion concerned is lot [13]. Carlo Menno et al., used Bio galvanized lizard technology, wherever the automaton will with success climb up to sixty-five (65)-degree slopes at 2cm / sec. however, the system cannot adapt to 3D circumstances and can't avoid obstacles [14]. B. L. Luka et al. utilized Vacuum suction essentially dependent on slippy edge strolling component innovation which may step over minor deterrents and reasonable payload capacity anyway its moderate and doesn't have a 3D progress.

Samuel G. Maggio created unmanned gadgets that will go on any vertical or modified surface which will be worked securely from the base. People aren't presented to hazardous statures or excessively perilous concoction or toxin climate**.** The International ascension machines made a device that will climb building structures and dividers by exploitation moving seal and vacuum grip to surfaces.

3. ROBOTIC SYSTEM

The wall-climbing robot (wcr) may likewise be raising PC that utilizes a suction cup technology, capable to mount up perpendicular smooth surfaces. It conjointly can defeat the most reduced (~ one mm) floor anomalies like bolt heads, welds, and so on. The experimental prototype developed with self- weight of 2 kg and additionally, it can take 1kg of payload. The created wcr goes at 0.7 m/min. the signify of effort is targeted on inference the propellant prerequisites tributary for the numerical framework style of the suction cup framework. The proportion of suction force and bearing on terrible suction pressure necessitate by method for the suction cup for securing the machine remotely is sorted out on paper and separated and the starter suction cup structure. The examination of suction components inside the suction cup is

required for analyzing the right suction elements to appear up to in any things and to hold fast to the floor with the perfect ensuring power.

3.1 Suction Cup Framework

The Suction cups are mostly utilized in wcr for smoothly operability and sticking on the wall surfaces. The required negative suction pressure is developed by the use of suction motor mounted with impeller design. Existing method of suction cup technology uses a centralized large suction generator to provide necessary negative pressure using lengthy cable, which makes the wcr unsuitable. This is because of the dynamic imbalance of the wall climbing robot and thereby affecting the stability of the robot. The developed suction cup framework is to avoid this imbalance and provide required negative pressure remotely attached with suction cup. This gives a remote operation for the wall-climbing robot. The given figure 1 depicts the mounting of suction motor with the suction cup. In addition, Figure 2 shows the simulated model by using Catia software for calculating the effective volume of air expelled by the suction generator.

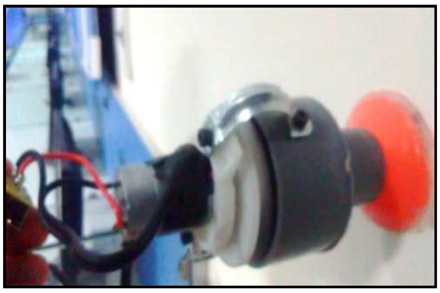

Figure 1: A Single Suction Cup Mounted with a Suction Motor.

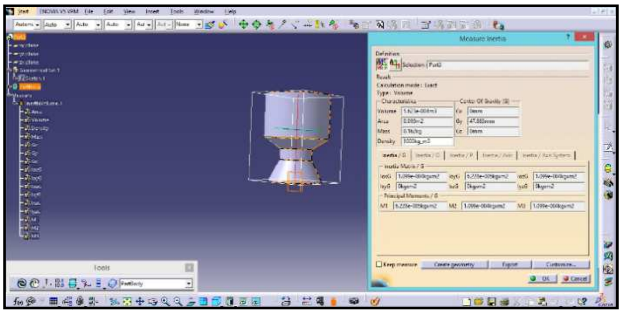

Figure 2: Simulated Model of the Suction Cup System by using Catia Software.

The mounting component is finished with one suction cup and a drive motor. The wall climbing robot traverse by implementing the method of hovercraft principle. For the numerical investigation, essentially a single suction cup framework is considered and furthermore, the detailed dimensions of the various associated elements are given in figure 3.

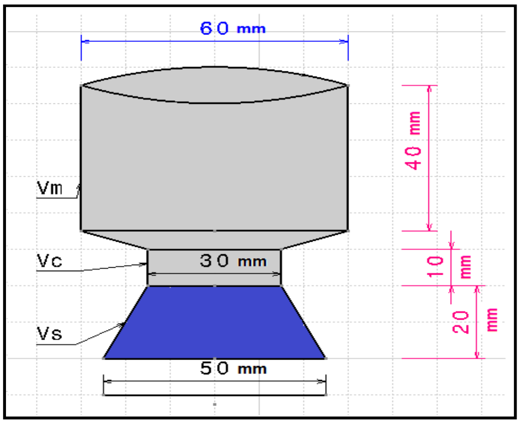

Figure 3: Dimensions of the Suction Cup System.

The suction cup is designed with a dimension of 50mm. The distinctive deliberate states accessible of suction cup depends on the speed of suction motor rotation. Depending upon the speed, the negative pressure varies and there by maintain the negative suction pressure required by the wcr to crawl on vertical wall surface.

3.2 Overseeing Conditions for Wall Climbing Robot

Notional parameters:

N_c – Reaction force applied by the cup

N_{w1}, N_{w2} – Reaction force applied by the drive wheels

f_C – Friction between wall and wcr chamber

f_{w1}, f_{w2} – Friction between the drive wheels and the wall

W – Wall climbing robot self –weight

h – Interspace from the wall to the focal point of gravity

L_1 – Posture of the wheels from modest border

L_2 – Posture between drive wheels and chamber

L_3 – Position of the chamber from the top edge

F_c – Suction power of the suction cup

μ – Static friction constant coefficient

Figure 4 shows the power balance outline for a solitary suction cup with drive wheel. For the reason, that evenness in the drive framework, $N_{w1} = N_{w2} = N_w$ [15].

Taking into consideration the Force balance,

X-axis:

$$N_c + N_{w1} + N_{w2} = F_c + 2F_w \quad (1)$$

Y-axis:

$$f_c + f_{w1} + f_{w2} = W = mg \tag{2}$$

Momentum on Point A:

Case 1: if the wcr suction chamber in fully hold condition

$$Wh = (L_1 + L_2)(F_c - N_c) - L_1(N_{w1} + N_{w2}) \tag{3}$$

Case 2: if the wcr suction chamber is in moving condition

$$\left.\begin{aligned} f_C &\le \mu N_c \\ f_{w1} &\le \mu N_{w1} \\ f_{w2} &\le \mu N_{w2} \end{aligned}\right\} \tag{4}$$

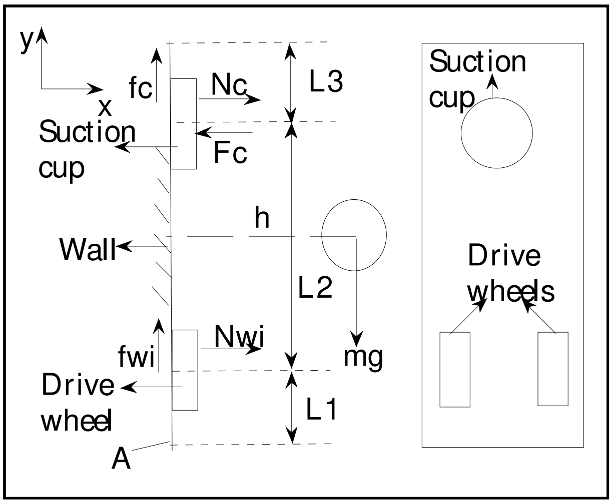

Figure 4: Force Balance Diagram.

Case 3: if the wcr suction chamber is in descend condition i.e., zero response forces applied to the suction cups can be secure from (1), (2) and (4) as

$$f_C + f_{w1} + f_{w2} \le \mu(N_c + N_{w1} + N_{w2}) \tag{5}$$

$$W \le \mu(F_c + 2F_w) \tag{6}$$

As the robot is going to fall the response power at the cup will in general zero i.e. $N_c = 0$ and so also is F_w i.e. $F_w = 0$.

Hence (1) and (3) will simplify to (7) and (8) respectively

$$(N_{w1} + N_{w2}) = F_c \Rightarrow 2N_w = F_c \tag{7}$$

$$\begin{aligned} &Wh = (L_1 + L_2)F_c - L_1(N_{w1} + N_{w2}) \\ &\Rightarrow Wh = (L_1 + L_2)F_c - 2L_1N_w \end{aligned} \tag{8}$$

Using (7) and (8),

$$Wh = (L_1 + L_2)F_c - L_1F_c \Rightarrow F_c = \frac{Wh}{L_2} \tag{9}$$

This demonstrates when the mass (= W/g) of this climbing robot will build the securing power required moreover increments, as can be envisioned.

The developed suction cup dimension is taken as $50mm$. Therefore, the negative pressure zone is of area, $A = 1.96 \times 10^{-3}$ m^2. In steady state condition, when the wcr is in rest, developed force, $F_c = 1.79$ N and when the wcr is in motion, i.e, traversing in vertical plane wall $F_c = 6.5$ N. Subsequently, the suction pressure in steady state is $-0.91kPa$ and $-3.316kPa$ respectively. By providing additional safety, this will be twice of the developed negative pressure, so as to maintain the stability of the robot.

3.3 Drive System

The locomotion is carrried out with a two drive wheels coupled with the single square gear drive motor of 7kgf torque with a shaft. The drive unit is placed by maintaining the centre of gravity of the motor and grants a speed of 0.7 meters/min. Figure 5 shows the extended read of the drive motor with drive wheel accommodated with extremely versatile rubber overlay for providing needed friction for movement and cut back the slip.

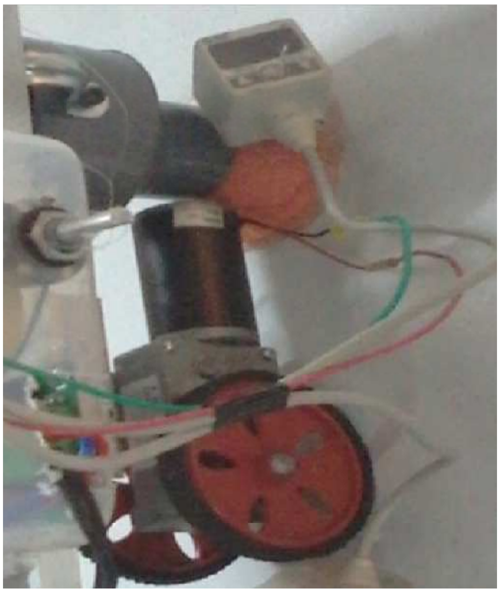

Figure 5: Drive System.

4. EMBEDDED CONTROL SYSTEM

The feedback based negative pressure control is the challenging aspects of designing the control system for climbing robot. The low cost Atmega microcontroller 328 is used for feedback control of suction pressure. The peripheral interfaces like sensor for measuring negative pressure, square gear motor for drive mechanism, mounted suction motor with impeller and High Definition Camera module for inspection. The interfaces and connected with the microcontroller for remote operation. A special algorithm is sketched in embedded microcontroller for the activity of the peripheral interfaces. This algorithm plays a role in developing required suction pressure to maintain the robot on wall surface without losing its mobility. The closed-loop feedback control is made utilized to overcome the surface irregularities. The schematic control is depicted in figure 6. The feedback receives the negative pressure data and

compares with the set point data to maintain proper adhesion capability. The block diagram of overall wall climbing robot peripheral is shown in figure 7.

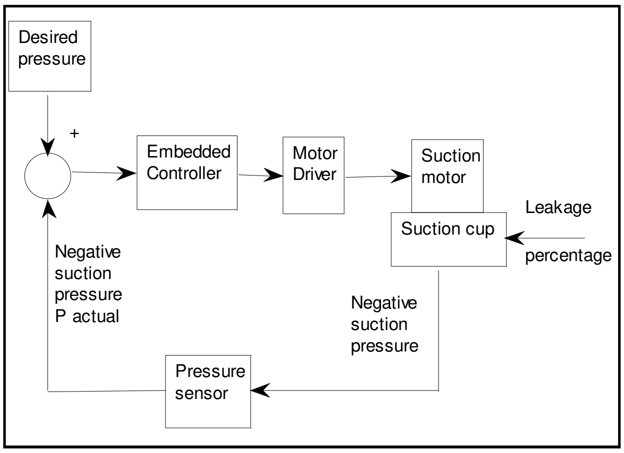

Figure 6: Negative Suction Pressure Controller – Basic Control Loop.

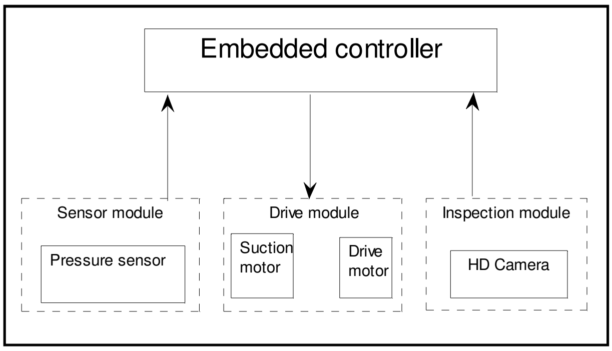

Figure 7: Block Diagram of Wall Climbing Robotic System.

5. WCR (WALL CLIMBING ROBOT) MODELLING

5.1 Matlab Simulation

The user friendly Simulink based PID control mechanism is shown in Figure. 8. Numerous blocks were used to style the Simulink model just as the DC motor with driver square, siphon, and the degree to watch the suction pressure. The information speed returning through the pivot of the DC engine is associated with the suction cup to think of the ideal suction pressure that is seen through the degree.

The wcr suction pressure is cultivated via dominating the momentum of the DC Motor with Proportional-Integral-Derivative (PID) controller. The negative feedback closed loop control mechanism works in turn to reduce or increase the speed of the suction motor based on the set point defined in the controller. Normally, when the suction motor impeller starts rotating, PID continuously monitors the response time and developed speed and changes according to the desired speed applied in the set point.

The PID tuner continues monitoring helps in regulating the pressure difference and thereby overcoming the irregularities in the surface.

$$V_{sm}(t) = K_{sm}.\Delta P_{sm}(t)$$
$$+K_{sm}.\frac{\Delta t}{T_{sm}}.\sum_{T=1}^{t}\frac{\Delta P_{sm}(T)-\Delta P_{sm}(T-1)}{2}$$
$$+K_{sm}.\frac{T_{sm}}{\Delta t}\left(P_{sm}^{act}(t)-P_{sm}^{act}(t-1)\right)$$

The on top of equation offers the inflammatory disease controller functions mistreatment the parts of proportional, integral and by-product constants wherever $V_{sm}(t)$ is the running speed of impeller developed by the suction motor.

$K_{sm}.\Delta P_{sm}(t)$ is dependent with proportional constant (K_p) of suction cup pressure.

$K_{sm}.\frac{\Delta t}{T_{sm}}.\sum_{T=1}^{t}\frac{\Delta P_{sm}(T)-\Delta P_{sm}(T-1)}{2}$ is dependent of Integral constant (K_i) of suction cup pressure.

The Auto tuning algorithm of PID generates the constants of proportional and integral with response in time in the Simulink model. The recreation algorithm is pre build function of PID controller, which is set to be constant as follows

$K_p = 1$, $K_i = 0$ and $K_d = 0$

The desired pressure simulated in the controller design of the Simulink model is shown in Figure 9, where 1 indicates the port to be simulated through the Simulink model of control design.

The results of the model are shown in Figure. 10 (a) and 10 (b) closed-loops with PID and closed-loop with minimum leakage percentage. The model is simulated for a single sliding suction cup.

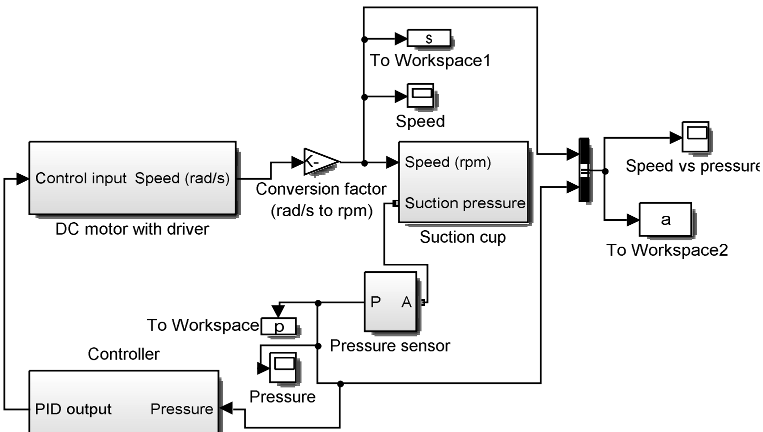

Figure 8: Simulink Model of DC Motor with Driver and Controller.

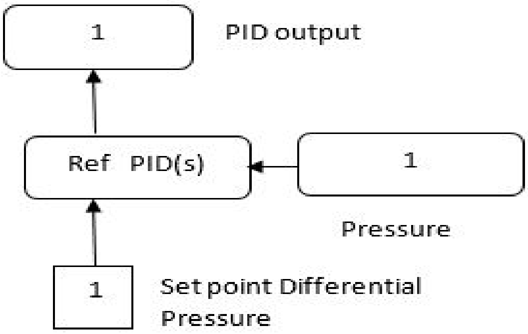

Figure 9: PID Controller with Desired Pressure.

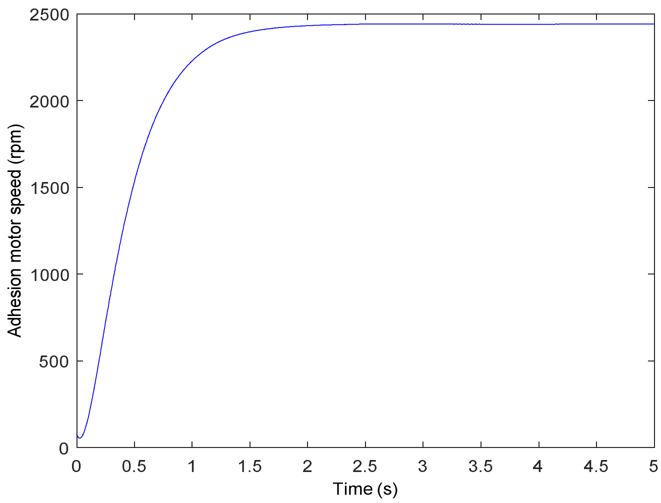

Figure 10: (a) Graph of Suction Motor Speed vs Time (with PID Controller).

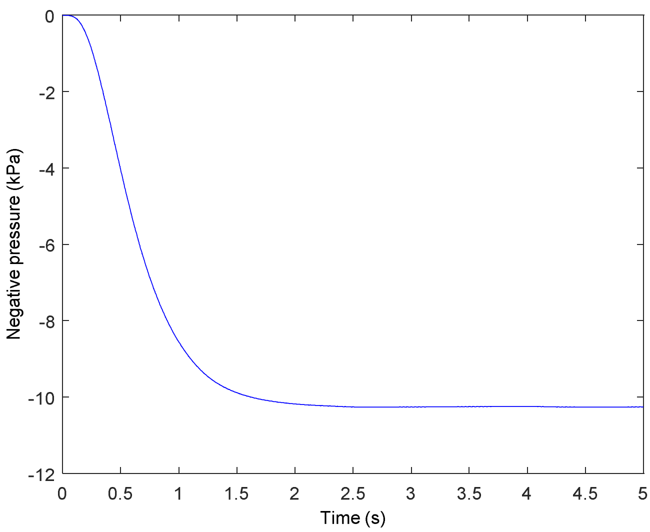

Figure 10: (b) Graph of suction Pressure vs Time (with PID controller).

Figure 11 shows the Simulink model observed with the PID controller giving a minimum percentage and leakage caused due to the gap. Figure 12 shows the result of the Simulink model when observed with the PID controller and the different leakage percentage.

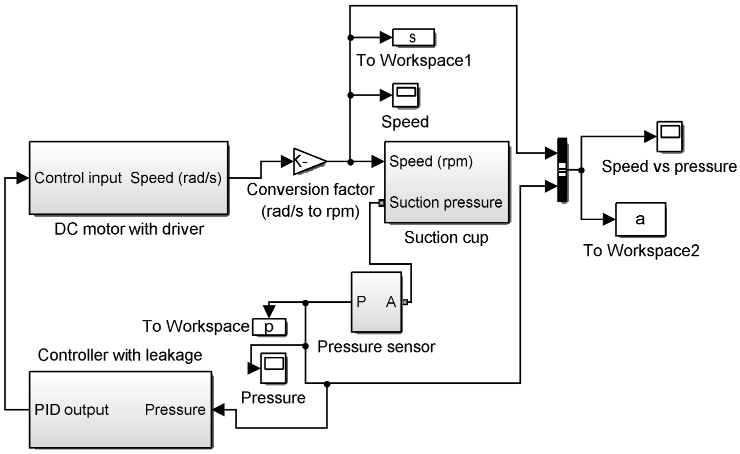

Figure 11: Simulink Model with Minimum Leakage.

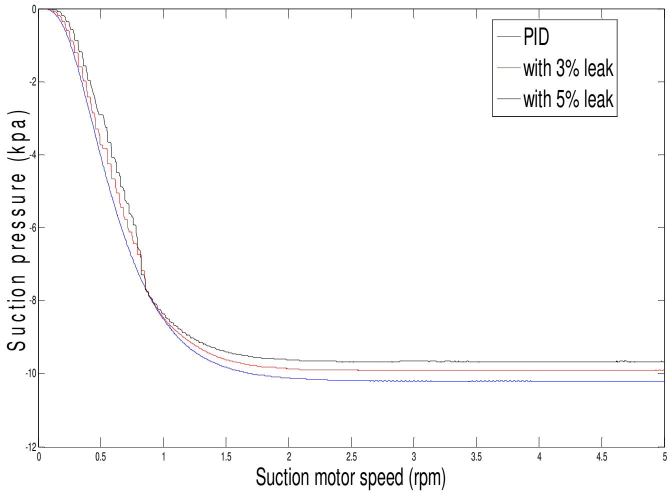

Figure 12: Comparison graph plot for Suction pressure vs Time with leakage of 3% and 5%.

6. EXPERIMENTAL RESULTS

WCR is designed especially to continually clean smooth surface-environment with a single suction cup. The suction cup has its suction engine to furnish fundamental attachment power. Figure 13 suggests the real-time experimental development of wcr. This examination is to achieve the characteristics of adhesion and locomotion for smooth mobility and stability of wcr. The role of wcr is to operate without losing its stability while traversing on vertical smooth surfaces.

Figure 13: Prototype of Wall Climbing Robot.

This simulation result is compared with the experimental data. The simulation is carried out in two ways: (a) Closed-loop with PID controller and (b) Closed-loop with PID controller and minimum leakage. The experimental data is shown in Table 1, represents the trend of increase in negative pressure concerning speed (which is anticipated).

Table 1: Experimental Data – Speed Vs Negative Pressure

Speed (RPM)	500	600	700	800	900	1000
Negative Pressure (kPa)	0.95	1.12	1.39	1.64	1.82	2.02

The experimental model conveys the weight off and for dynamic sliding and holding the component, while the Simulink accomplishes the weight of generally with controller. For the prototype, wcr weighs of 2 kilograms of mass. The Simulink test performs the maximum pressure loss of 5 percent, which will be the drop-off pressure for wcr. It is moreover decided in recreation that by setting the controller and wanted strain to be 10, the maximum pressure achieved by neglecting the leakage is around $-11kPa$.

7. CONCLUSIONS

The overall paper presents the outlay of development of wall climbing robot for smooth surface transition. The analysis includes the smooth operation in vertical plane surface of minimal disturbance. This method achieves the aero drag principle of methodology. The slip to pressure leak ratio is compared with the drive wheel and aerodynamic pressure. The locomotion capability can go up to the speed of 0.7 meters/min. the prolonging time acquainted by the controller with the objective that the speed of suction generator ought to be diminished for safe maneuverability of wall climbing robot. The design of embedded controller optimization rules in reduction of self-weight and carrying extra payload for high domain inspection. The future direction of this research aims in design of impeller selection for high negative pressure generation.

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Navaprakash N got his Bachelor Degree (B Tech) in Electronics and Communication engineering, from Pondicherry University in the year 2013. In the year 2016, He received his Master degree (M Tech) in Industrial Automation, from Hindustan Institute of Technology and science, Chennai and currently pursuing Ph.D. degree in Robotics, Control and Automation respectively. His major field of interest deals with Robotics, Control engineering, Embedded system design, Automation and wireless communications. As a part of his research, From mid-2016 onwards, He is presently working as a Senior Research fellow in Government funded project undertaken by Centre for Sensors and Process Control (CENSE), Hindustan institute of Technology and Science, Chennai, India. His major contribution is development of control algorithms and research ideas in embedded designs. He also actively participated in many other project events in university

level. As part of his Ph.D. research, He presented his research findings in International conferences and got two Scopus indexed publication. In spite of this, He got an opportunity for a live demonstration of developed wall climbing robot before eminent scientists all over the world in IEEE Sensors flagship conference. He is currently having two Scopus indexed publications. Apart from his research in development of wall climbing robot, he also contributed his role in Electrical and Electronics related research projects.

Uppu Ramachandraiah got his Master's degree (M Tech) in Electronics and Instrumentation Engineering from National Institute of Technology (NIT), Warangal, India and Doctor of Philosophy degree (Ph.D.) in Signal Processing from Indian Institute of Technology Madras (IIT M), Chennai, India, in 2001 and 2010, respectively. Currently, he is working as Professor& Head, School of Electrical Sciences, Hindustan Institute of Technology and Science, Chennai, India. Prior to this, he served thirty plus years as Senior Scientific Officer at Bhabha Atomic Research Centre Facilities, Department of Atomic Energy, India. He is presently guiding eight research scholars in various multidisciplinary domains. He is also a Principal investigator in many government-funded research projects undertaken by Centre for Sensors and Process control (CENSE), Hindustan Institute of Technology and Science, Chennai, India. Apart from his work, He is also a member in many professional bodies like IEEE. As part of research activities, He published around more than 10 National and International journals indexed in Scopus and participated in approximately 12 National and International Conferences. Presently, He is also serving as Editorial member in reputed journals. His research interests includes Process Control & Instrumentation, Robotics and Automation, Industrial Automation, Real-time Embedded Systems and Real- time Signal Processing.

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funded research projects undertaken by Centre for Sensors and Process control (CENSE), Hindustan Institute of Technology and Science, Chennai, India. He is presently guiding two research scholars in different fields of Bio-medical and Electrical engineering. Apart from his work, He is also a member in many professional bodies like IEEE. As part of research activities, He published around 5 National and International journals indexed in Scopus and web of Science and participated in more than 5 National and International Conferences. Presently, He specializes in PLC, SCADA and DCS Systems, Robotics and Automation and focus primarily on Embedded System Design with novel ideas on sensor data acquisition and control.